Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

Northern Illinois Center for Accelerator and Detector Development

Plan for *X*- and *g*-ray production at the Fermilab Accelerator Science & Technology (FAST) facility

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CHANNELING 2016

7th International Conference

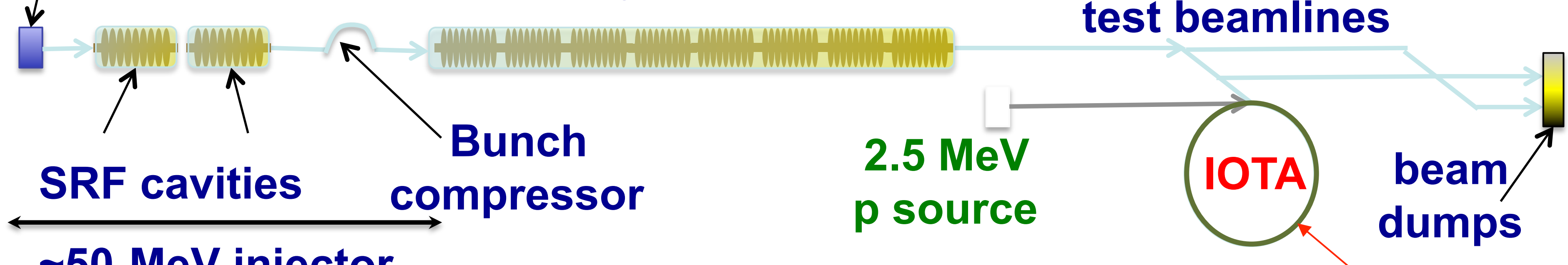
Charged & Neutral Particles Channeling Phenomena

Credits

- **Channeling radiation:**
  - FNAL: D. Edstrom, J. Ruan, T. Sen, A. Romanov, V. Shiltev,
  - NIU: A. Halavanau, D. Mihalcea
  - HZDR (Dresden): W. Wagner
  - U. Sokendai: J. Hyun
- **Gamma-ray development**
  - FNAL: J. Ruan,
  - NIU: A. Halavanau, A. Khizakhov, D. Mihalcea, M. Urfer
  - RadiabeamTechnologies: A. Murokh, B. Jacobson

***Graduate students**

The FAST/IOTA complex



~300-MeV e- linac section

RF gun

cryomodule

test beamlines

SRF cavities

Bunch compressor

2.5 MeV p source

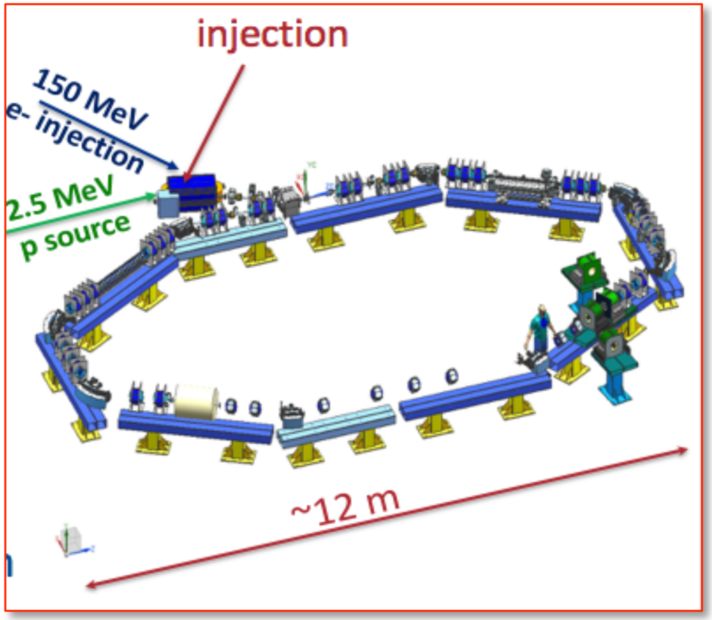
IOTA

beam dumps

~50-MeV injector

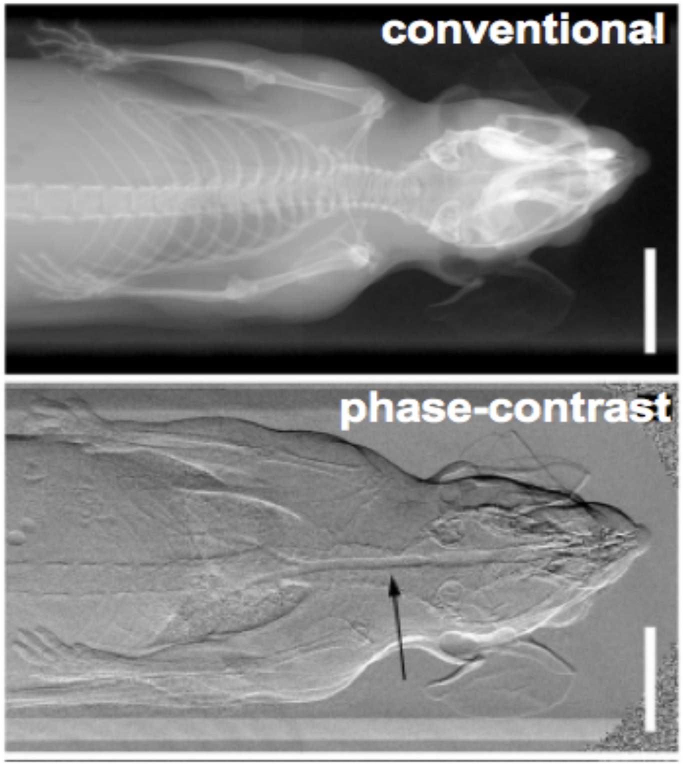
- FAST-IOTA facility complex includes:
  - IOTA (integrable-optics test accelerator) ring,
  - An electron linear accelerator (that nominally serves as an **electron injector** to IOTA),
  - A **proton source & injector** for IOTA
- Facility is located in the New Muon Lab (NML) building

http://fast.fnal.gov/



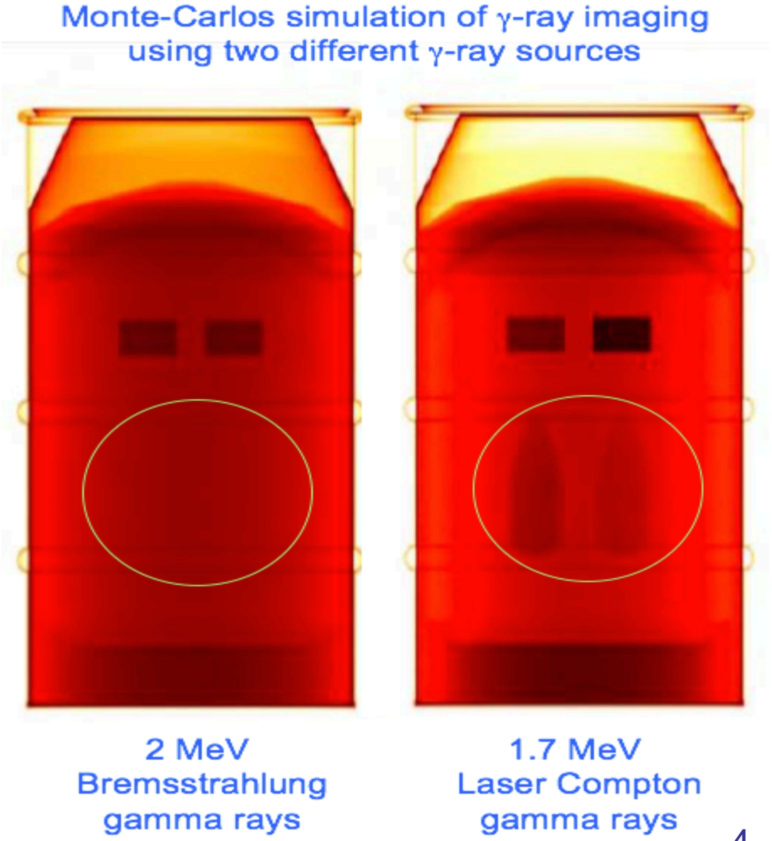
X- & g-ray programs at FAST

- Channeling radiation:
  - Demonstrate high-brilliance **X-ray**
- Application: imaging



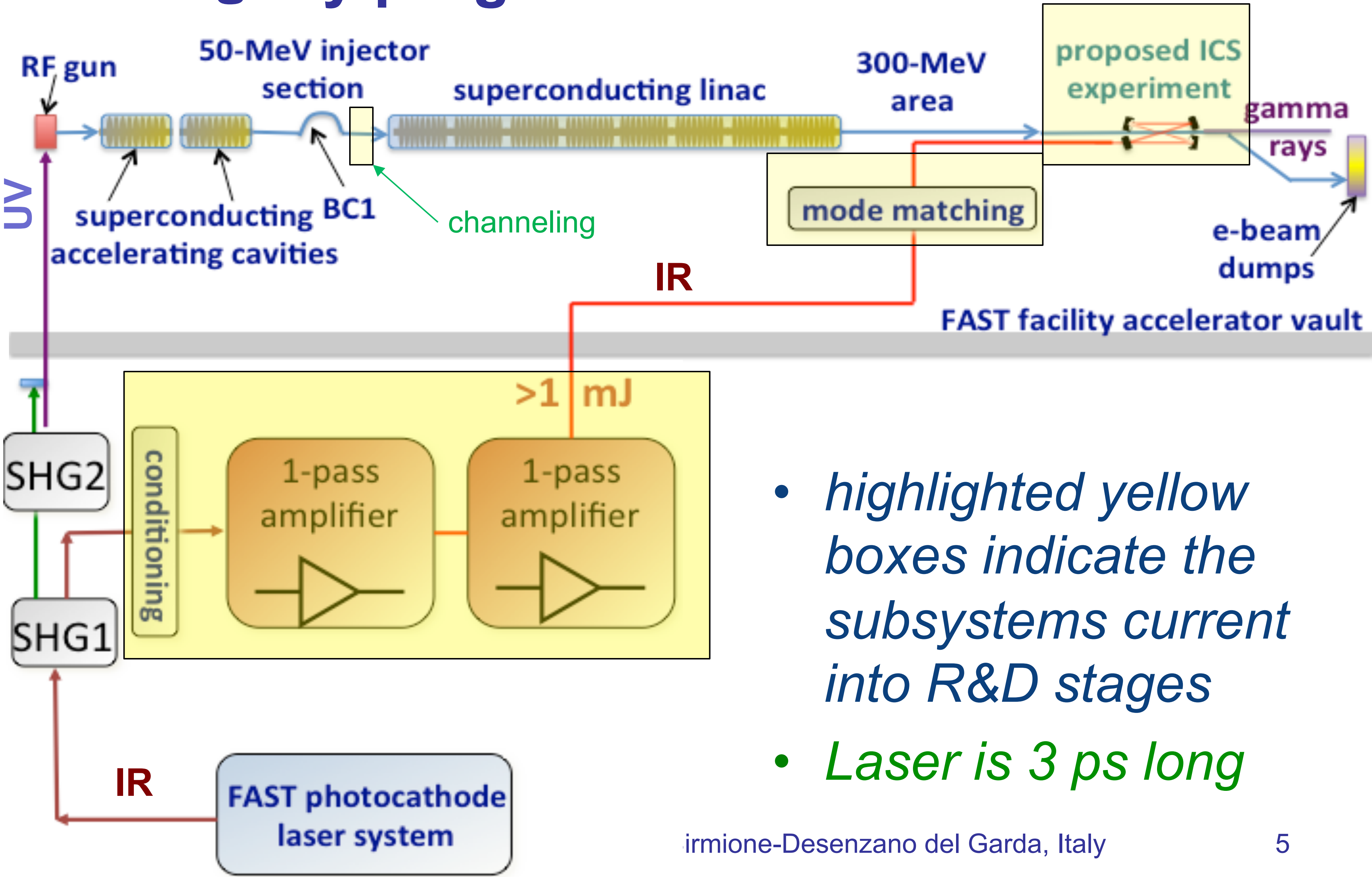
M.Bech et al., Sci. Rep. **3**, 3209 (2013)

- Inverse Compton Scat.:
  - Demonstrate high-brilliance **g ray**
- Application to security



Simulations from L. Barry, LBNL (2008)

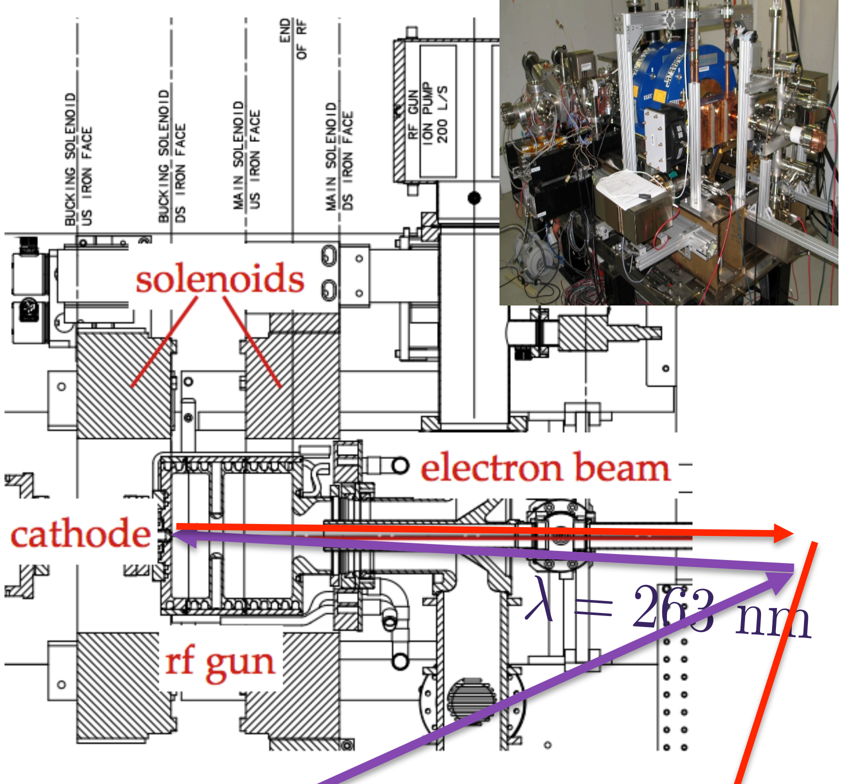
Overview of the FAST facility and its X- & g-ray programs



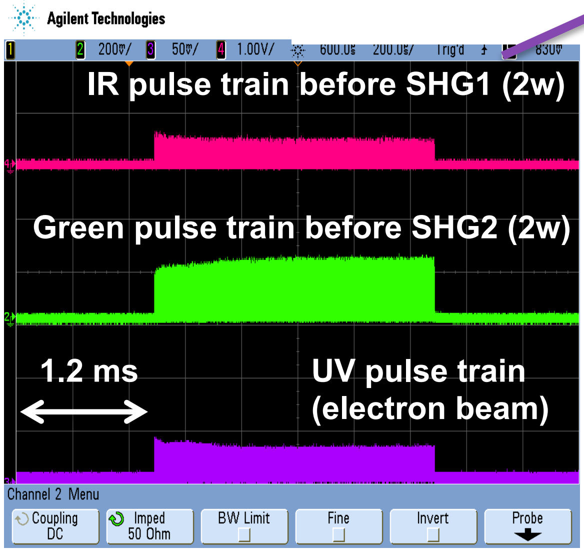
- *highlighted yellow boxes indicate the subsystems current into R&D stages*
- *Laser is 3 ps long*

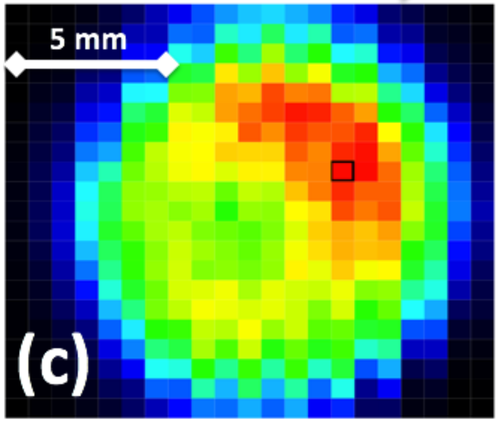
Electron Source

- e- source based on a radio-frequency (RF) gun coupled to
  - A high-power laser
  - A high-quantum efficiency photocathode (Cs_2Te)
- Capable of forming high-brightness electron beams arranged as bunch trains



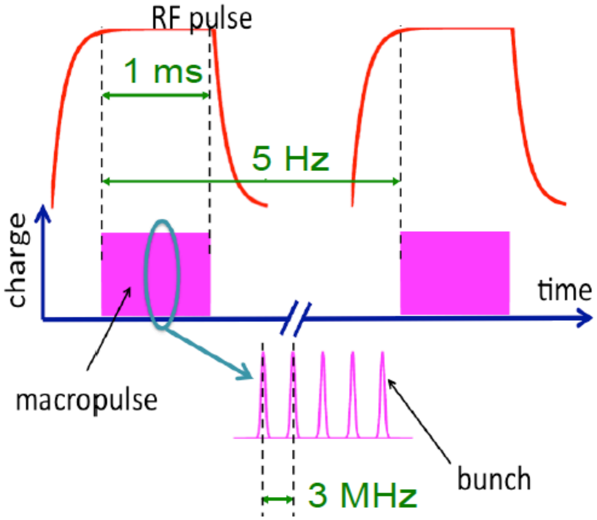
Parameter	Value	Unit
Bunch charge	0.02 – 3.2	nC
Bunch train duration	1	ms
Bunch frequency within train	3	MHz
Number of bunches/train	1 – 3000	
Bunch train frequency	1 – 5	Hz



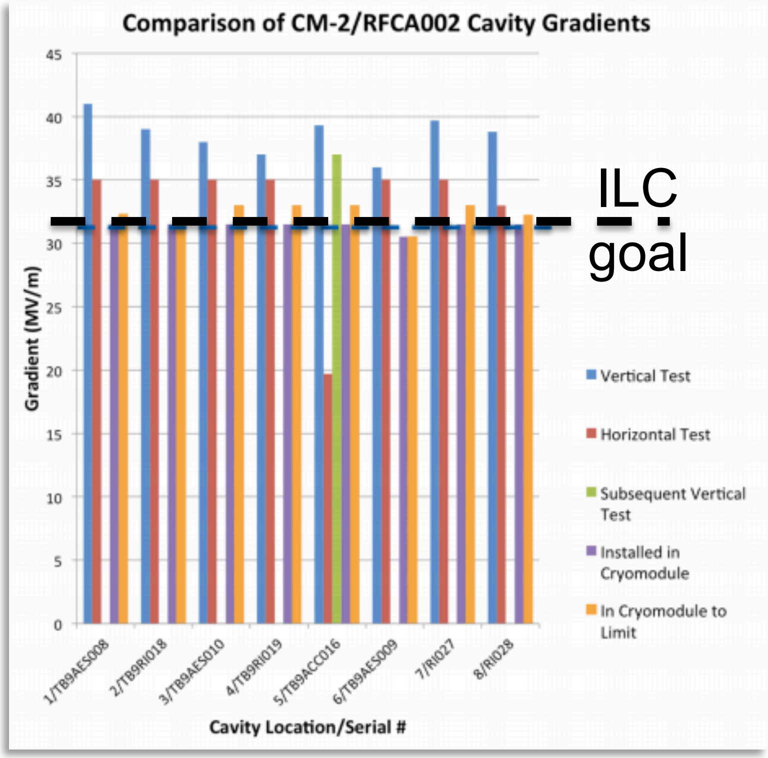


Acceleration to ~300 MeV

- The 50-MeV beam is accelerated in a cryomodule (a string of 8 SCRF cavities)
- Produced *stable* beams with energies up to 300 MeV arranged as macropulses.

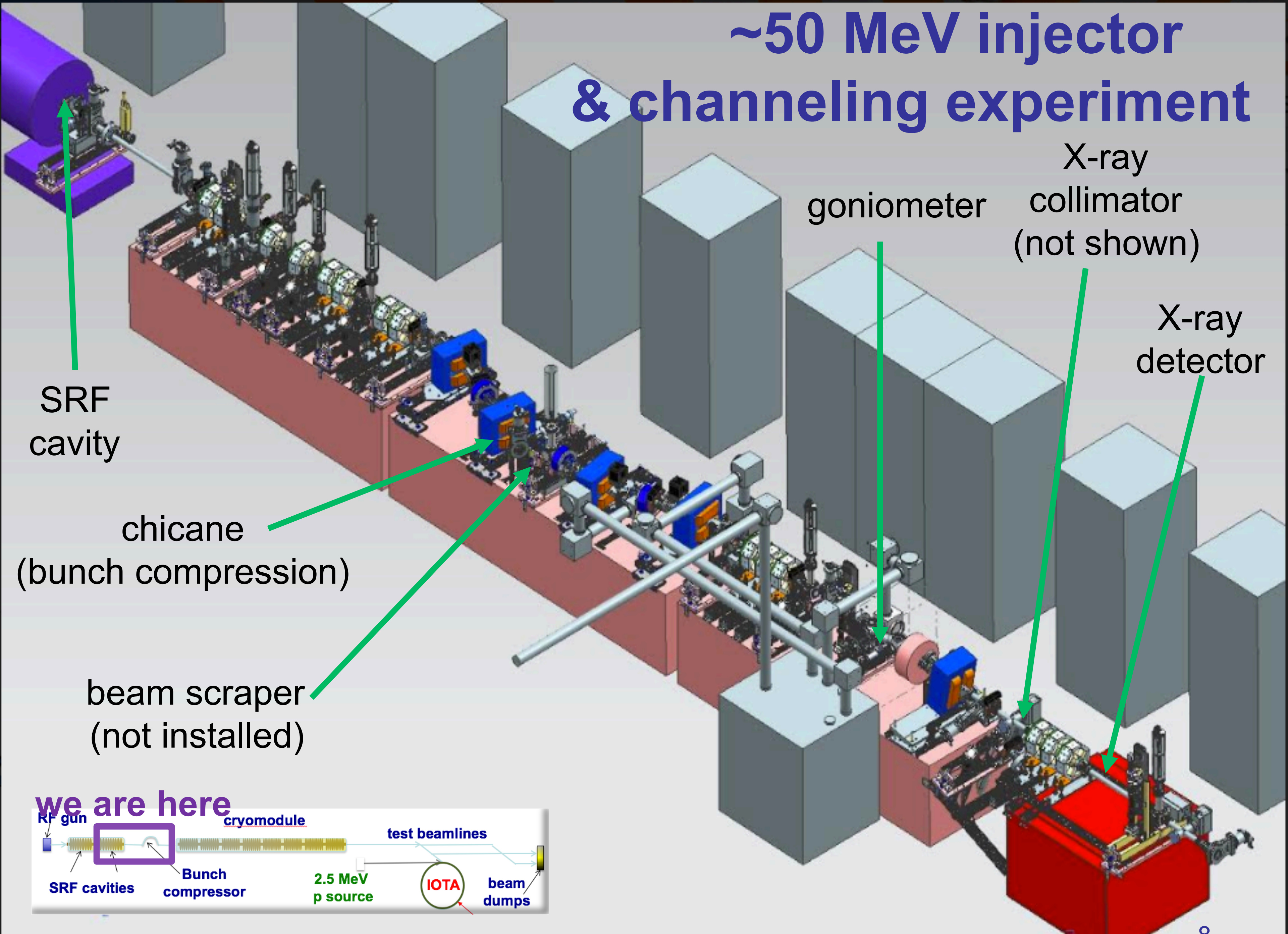


- Expected Spring 2017.



[E. Harms, et al. SRF2015 (2015)]

~50 MeV injector & channeling experiment



SRF cavity

chicane (bunch compression)

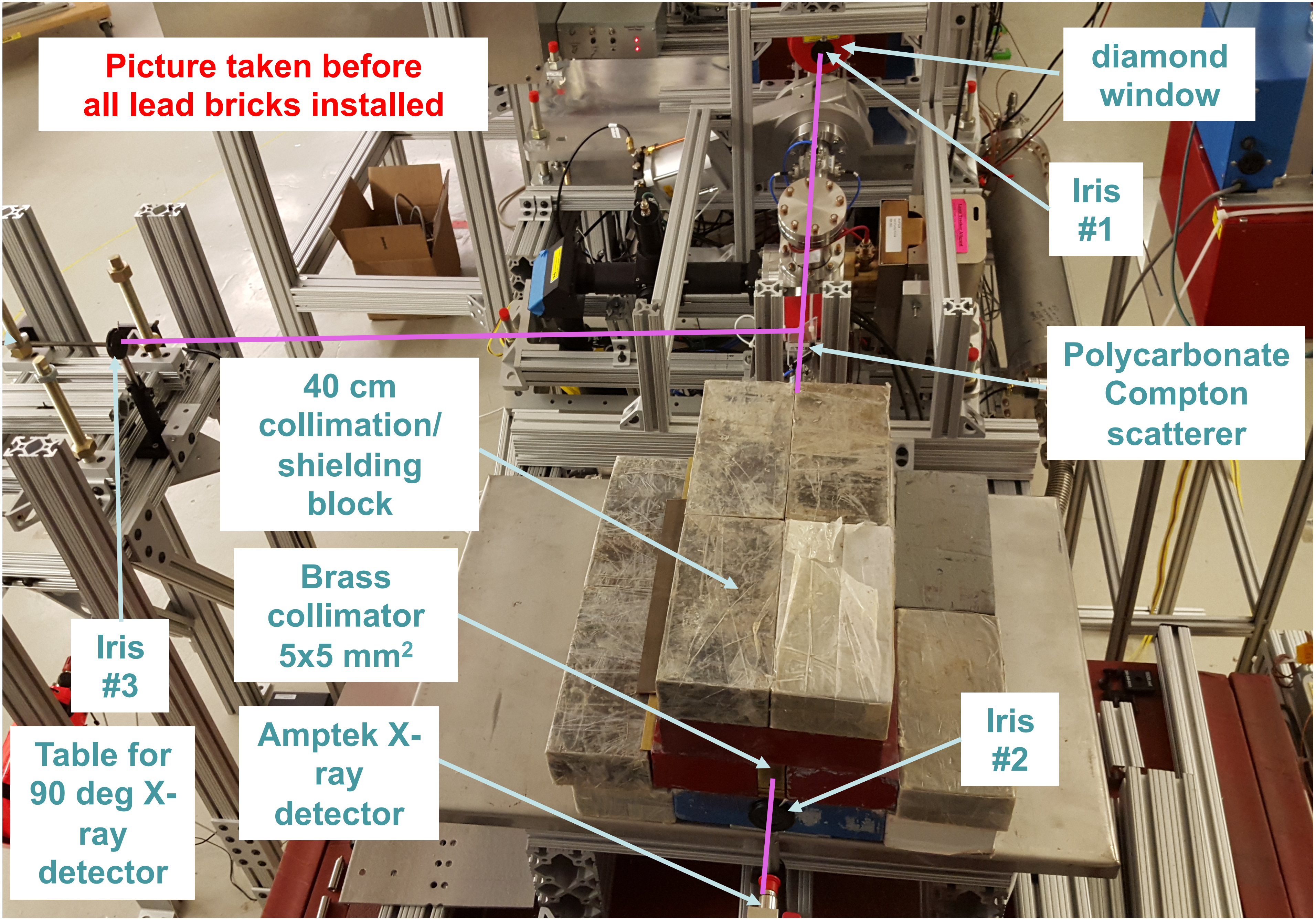
beam scraper (not installed)

goniometer

X-ray collimator (not shown)

X-ray detector

we are here



Picture taken before all lead bricks installed

diamond window

Iris #1

Polycarbonate Compton scatterer

40 cm collimation/ shielding block

Brass collimator 5x5 mm^2

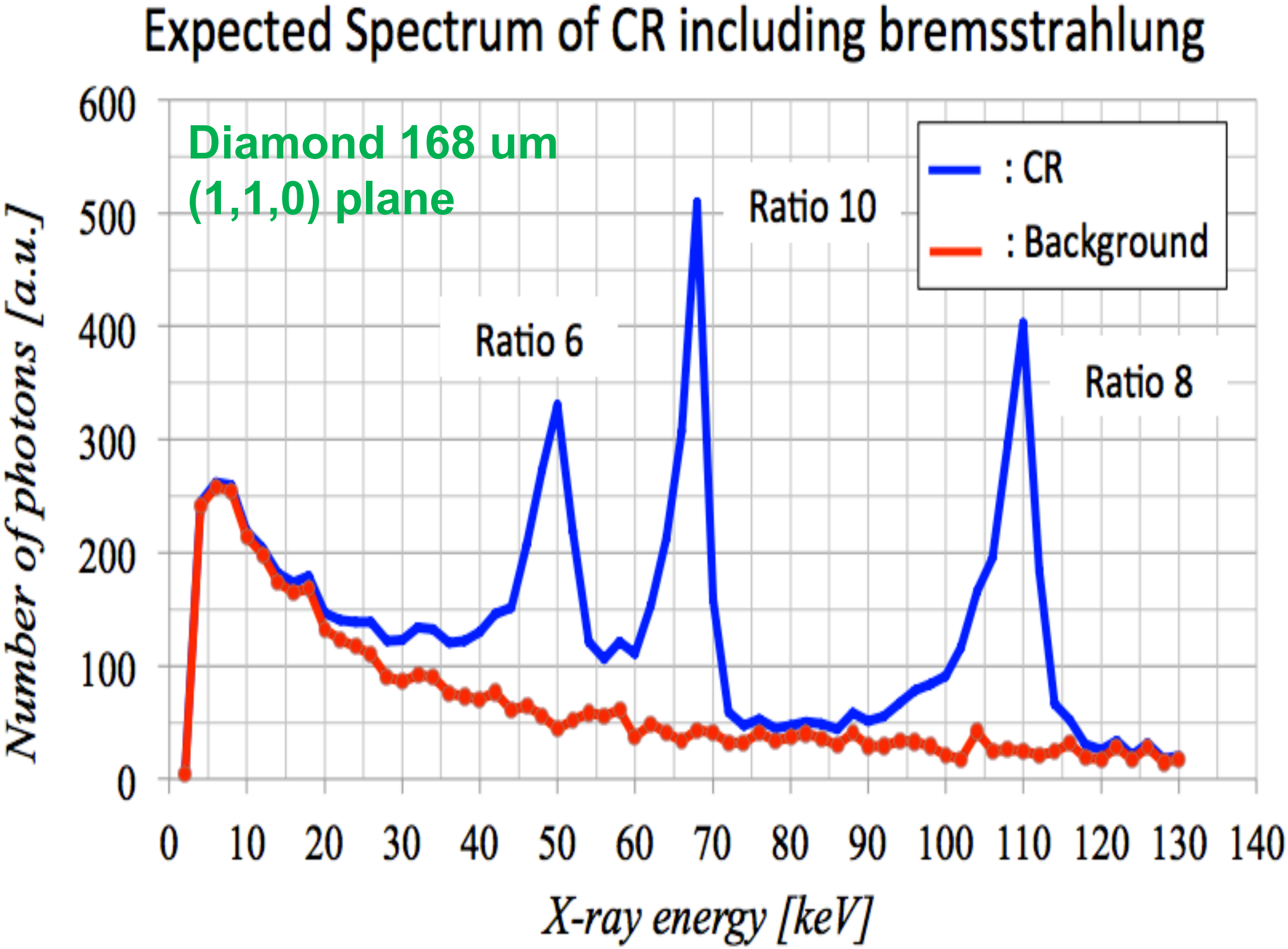
Iris #3

Iris #2

Amptek X-ray detector

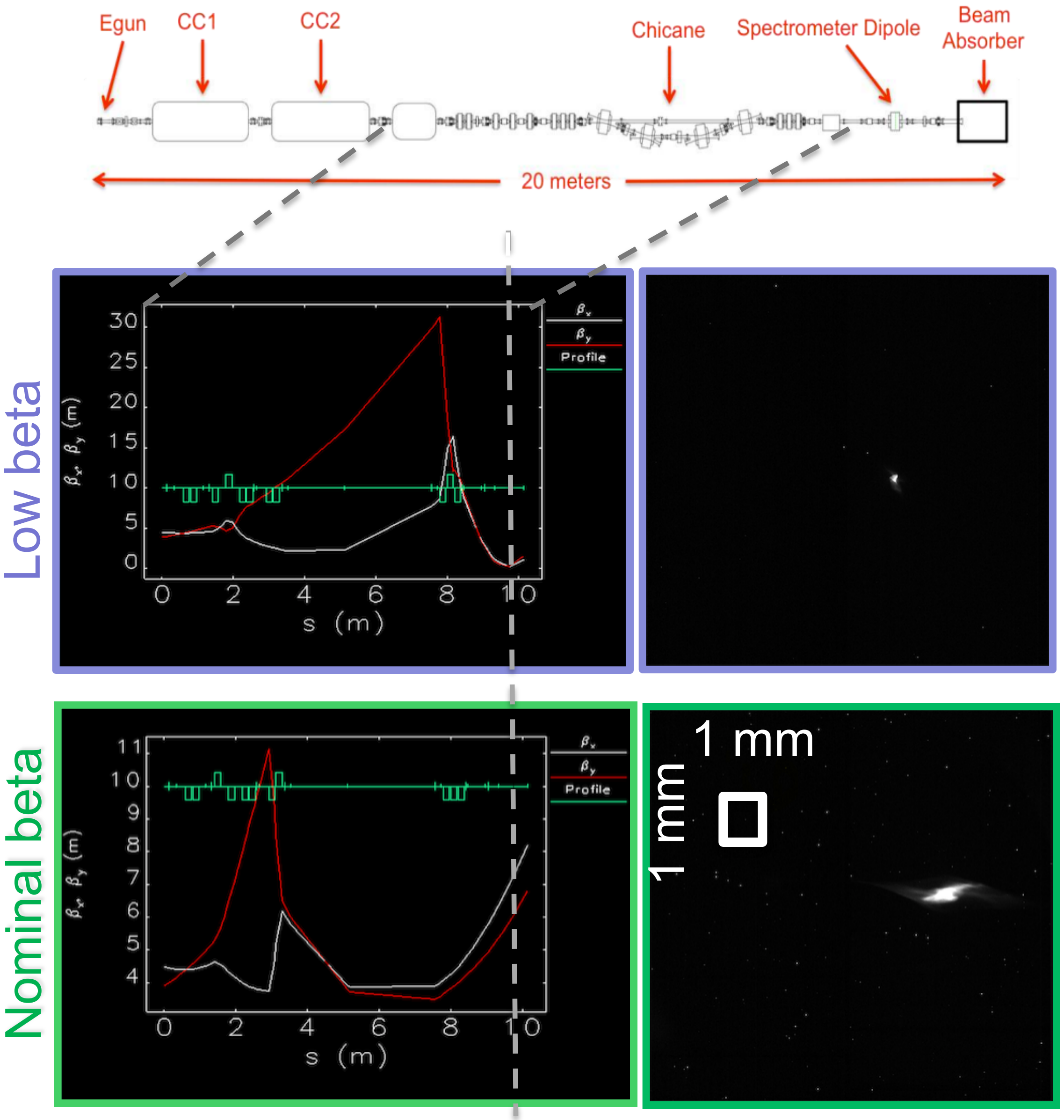
Table for 90 deg X-ray detector

Expected spectrum at 43 MeV



Acceleration to 50 MeV (done June 2016)

- e- source is coupled to two SRF cavities
- Beam accelerated to 50 MeV (5/17/16)
- Characterization and beam control coupling machine control system to simulation (6/4/16)
- Measured beam emittances higher than expected (optimization still needed)

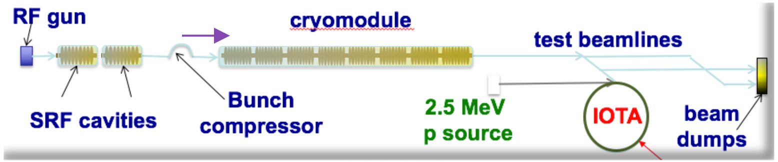


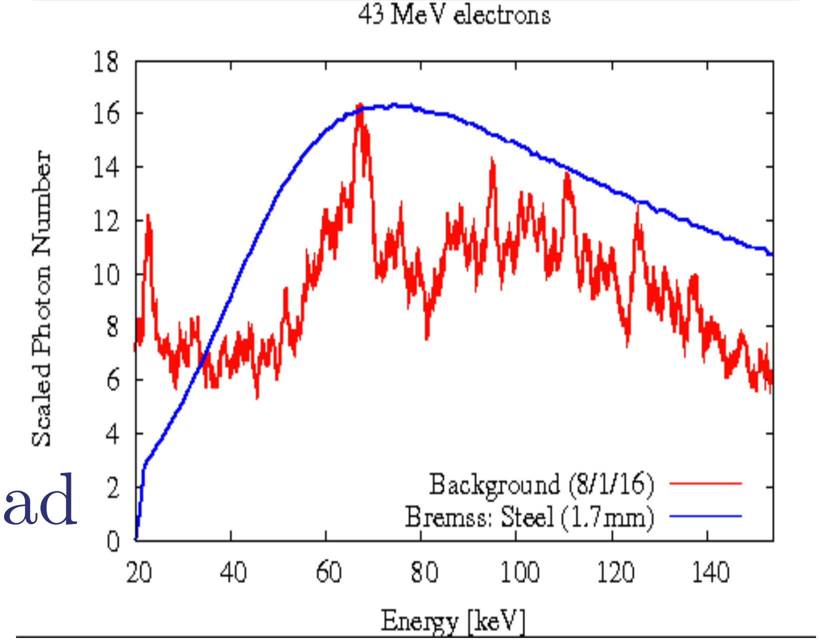
Issues & Lessons learn so far

- **Channeling radiation occurred in parallel to commissioning of the 50 MeV injector**
  - Injector performed very reliably
  - Dark current was a limiting factor:
    - Dark current had same energy as the main beam.
    - chicane scraping led to large background (bremss.)
  - Acceptable beam parameters were produced

$$\sigma_\perp \simeq 100\ \mu\mathrm{m}\ \sigma'_\perp \simeq 300\ \mu\mathrm{rad}$$

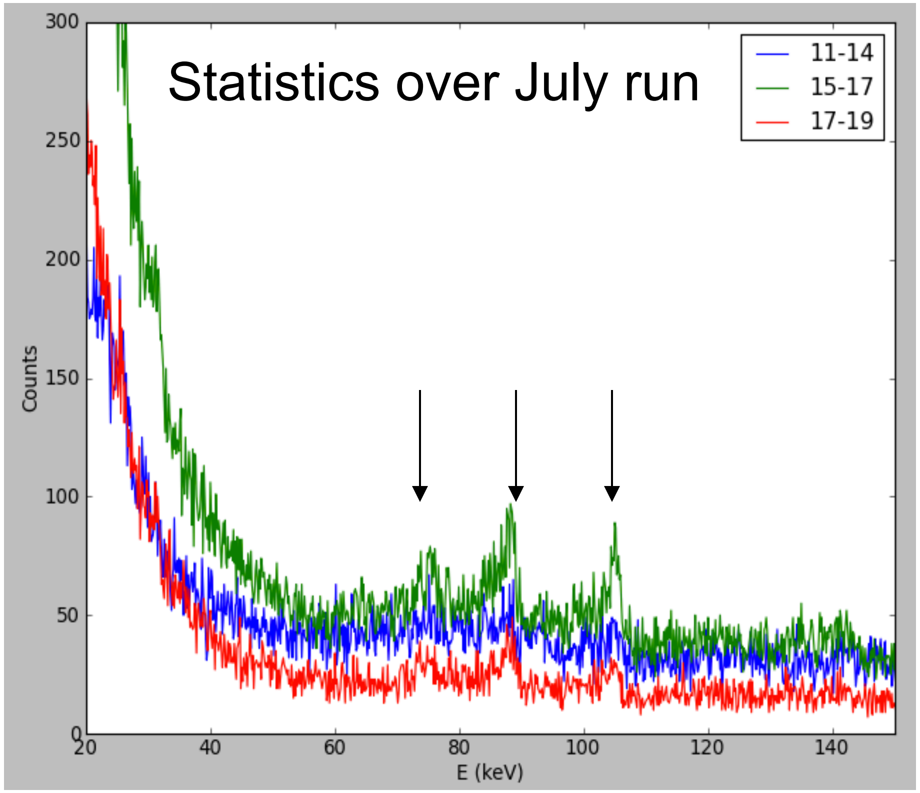
  - Detector not fully understood





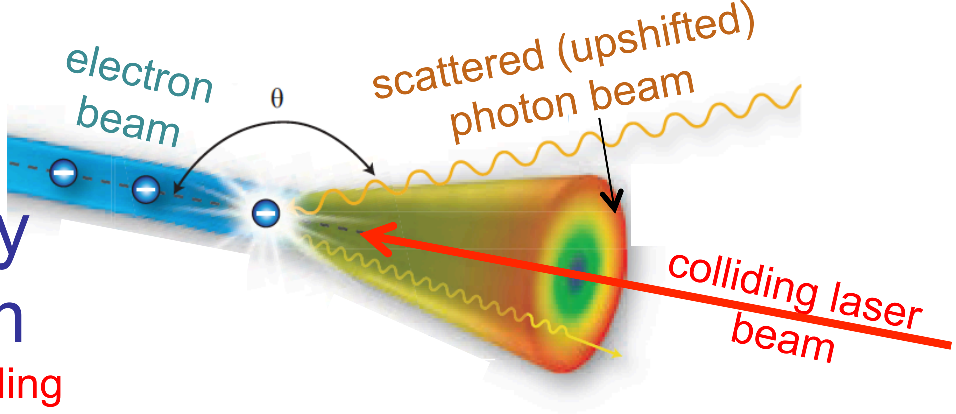
Results so far (not understood!)

- So far did not observe any channeling during acquisition.
- As posteriori analysis (summing large number of spectra) show some spectral lines.
- **does not correspond to our simulations!**
- Need to reconfigure experiment for possible run later in the year.



Promises of ICS @FAST

[adapted from OSA]



- properties of frequency upshifted photon beam
  - energy

final photon energy

colliding laser photc energy

$$E_\gamma \simeq 4\gamma^2 E_L$$

e-beam Lorenz factor (energy)

  - total photon flux

# of g photons

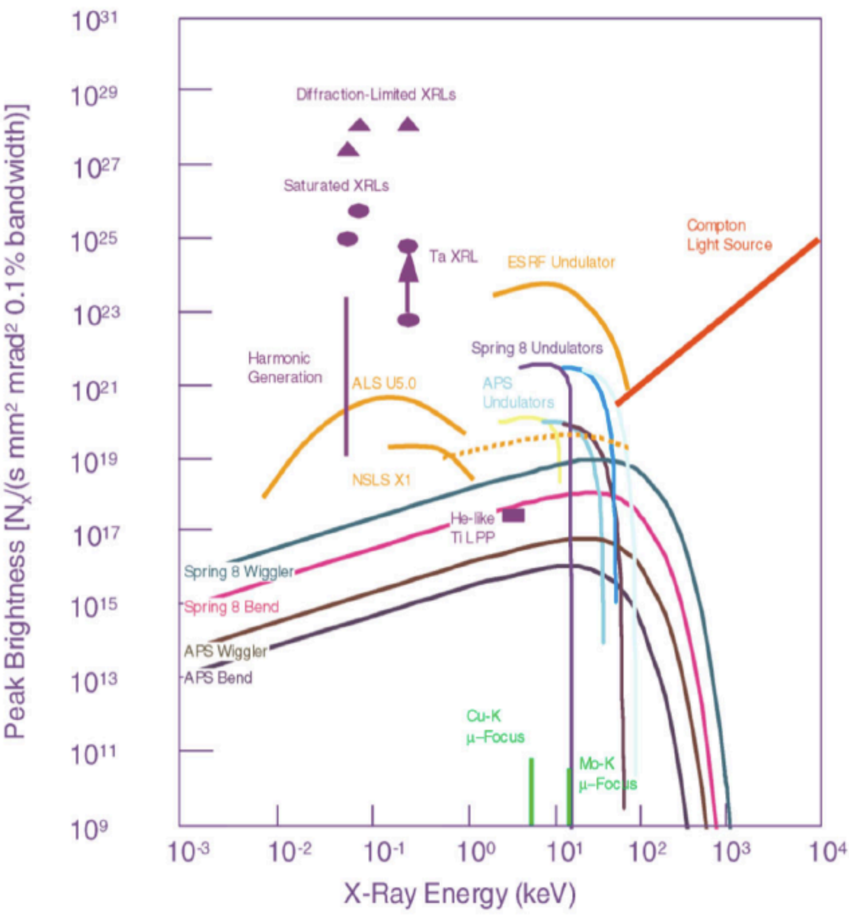
e-

colliding photon

suppression factor <1

$$N_\gamma = \frac{N_e N_L \sigma_T}{2\pi\underbrace{(\sigma^2_{\perp,L} + \sigma^2_{\perp,e})}_{}}F$$

sizes of colliding laser (L) and electron(e) beams



[F. Hartemann et al. PRSTAB **8**, 100702 (2005)]

Motivation

- Overarching goal: demonstrate and characterize a high-flux g rays using ICS
- Do not focus on electron source development:
  - use an available state-of-the-art superconducting linac: ultra-stable electron beam with controllable parameters (energy, energy spread, emittance, charge,…)
- Use an available electron beam to perform high-rep rate ICS
  - upgraded laser system to provide necessary energy and rep. rate for high-rep-rate ICS
- R&D is complementary to on-going R&D in, e.g. LPWFA

Brightness in
phot./sec/mm/mrd/0.1% BW

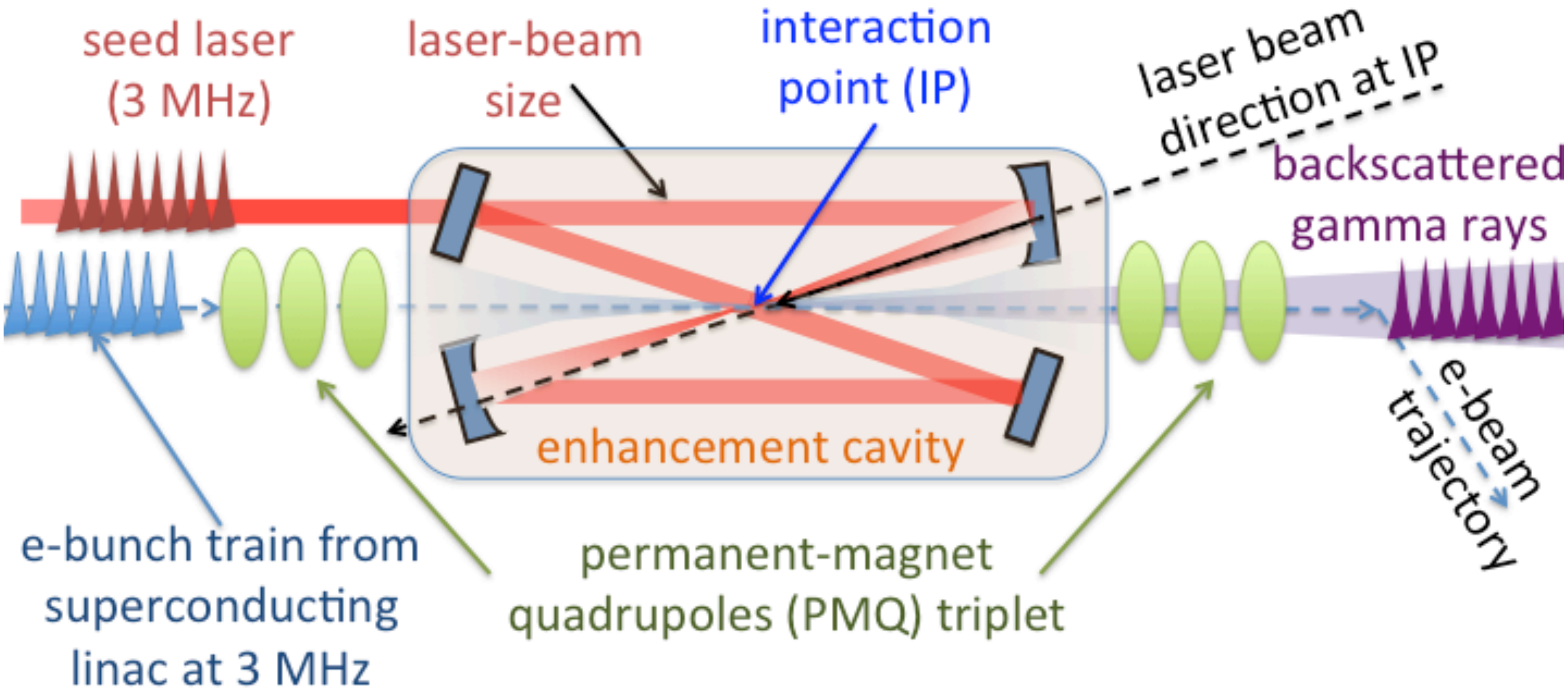
$$\mathcal{B} \propto N_\gamma f_c$$

# of g
photons

# of collision
per sec
1 to 15,000 at
FAST

Principle

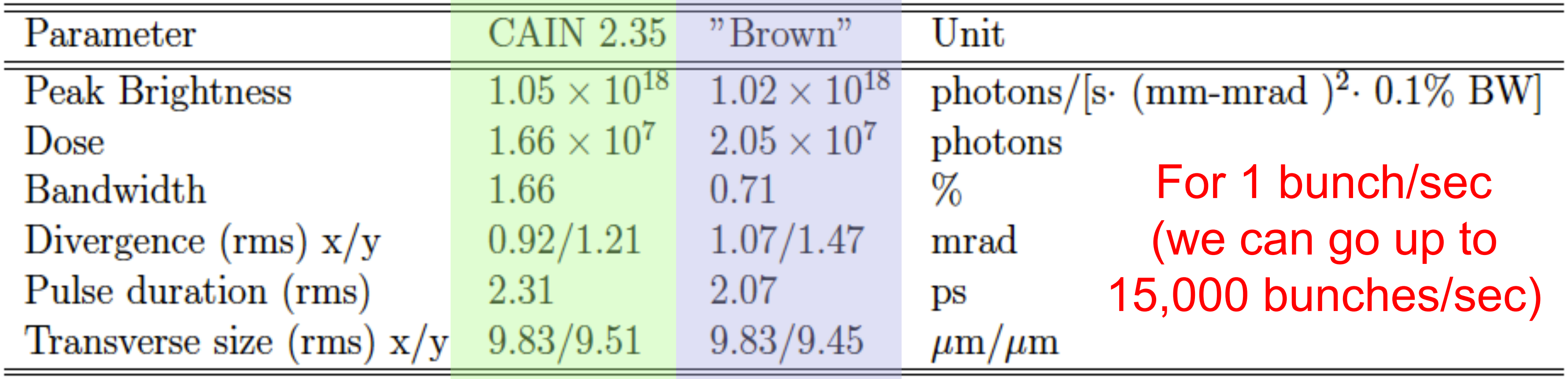
- Laser pulse is injected in a high-finesse optical cavity to build up its energy (coherent stacking)



- cavity could be adapted for use with LPWFAs

Comparison of simulation codes

- Detailed modeling of the ICS interaction with 2 programs (classical vs quantum electrodynamics descriptions)
- codes in agreement + confirm our earlier brightness estimate of ~ 10^{18} (for 1 e- bunch) corresponding to 10^{22} for 15000 e- bunches/sec)



Parameter	CAIN 2.35	"Brown"	Unit
Peak Brightness	1.05×10^{18}	1.02×10^{18}	photons/[s· (mm-mrad $)^2$· 0.1% BW]
Dose	1.66×10^{7}	2.05×10^{7}	photons
Bandwidth	1.66	0.71	%
Divergence (rms) x/y	0.92/1.21	1.07/1.47	mrad
Pulse duration (rms)	2.31	2.07	ps
Transverse size (rms) x/y	9.83/9.51	9.83/9.45	μm/μm

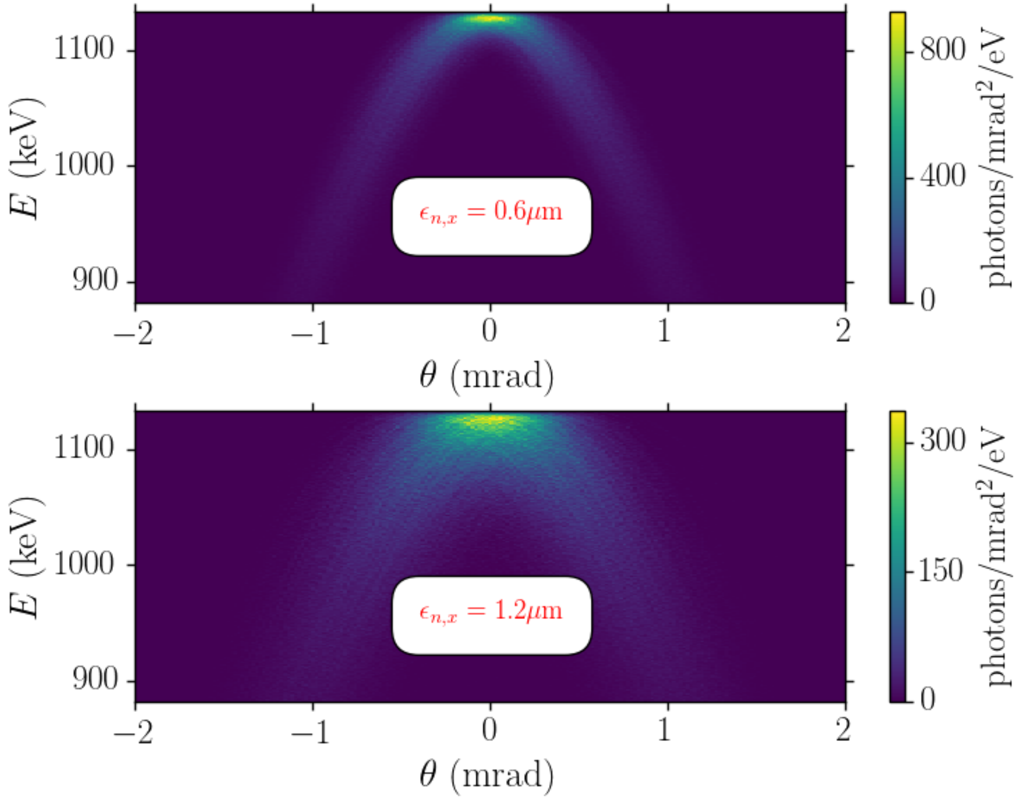
For 1 bunch/sec (we can go up to 15,000 bunches/sec)

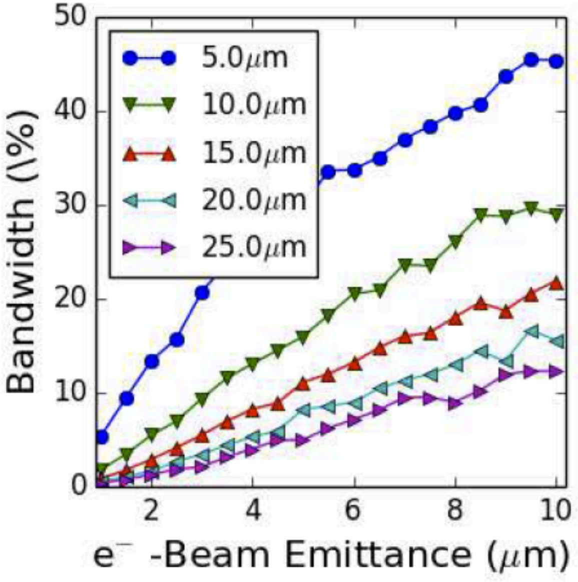
QED

classical

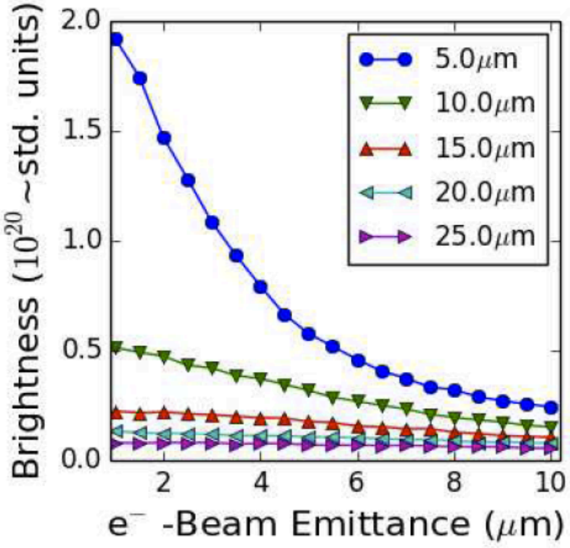
Parametric studies

- parametric investigation of g-ray properties to guide on a possible interaction-region design

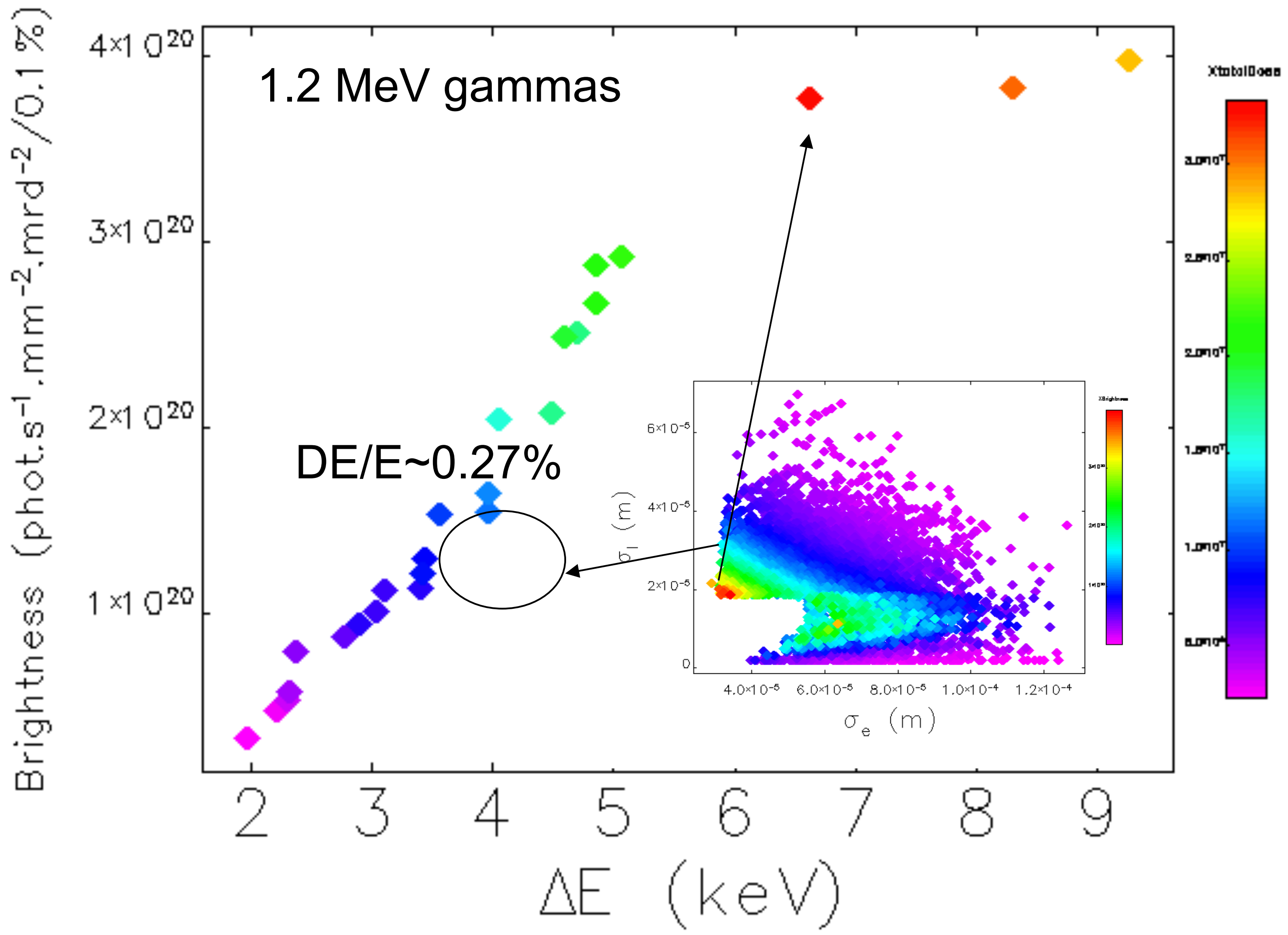




radiation parameters versus beam emittance for 5 cases of electron-beam transverse size

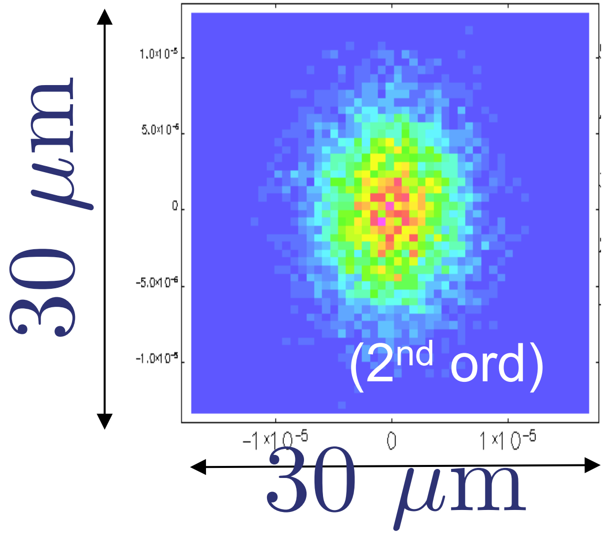


g-ray brightness optimization

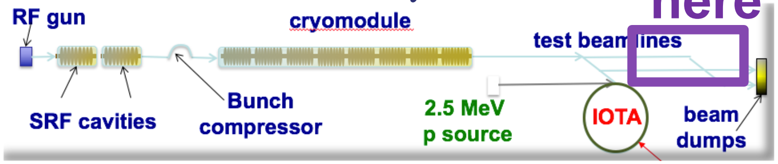


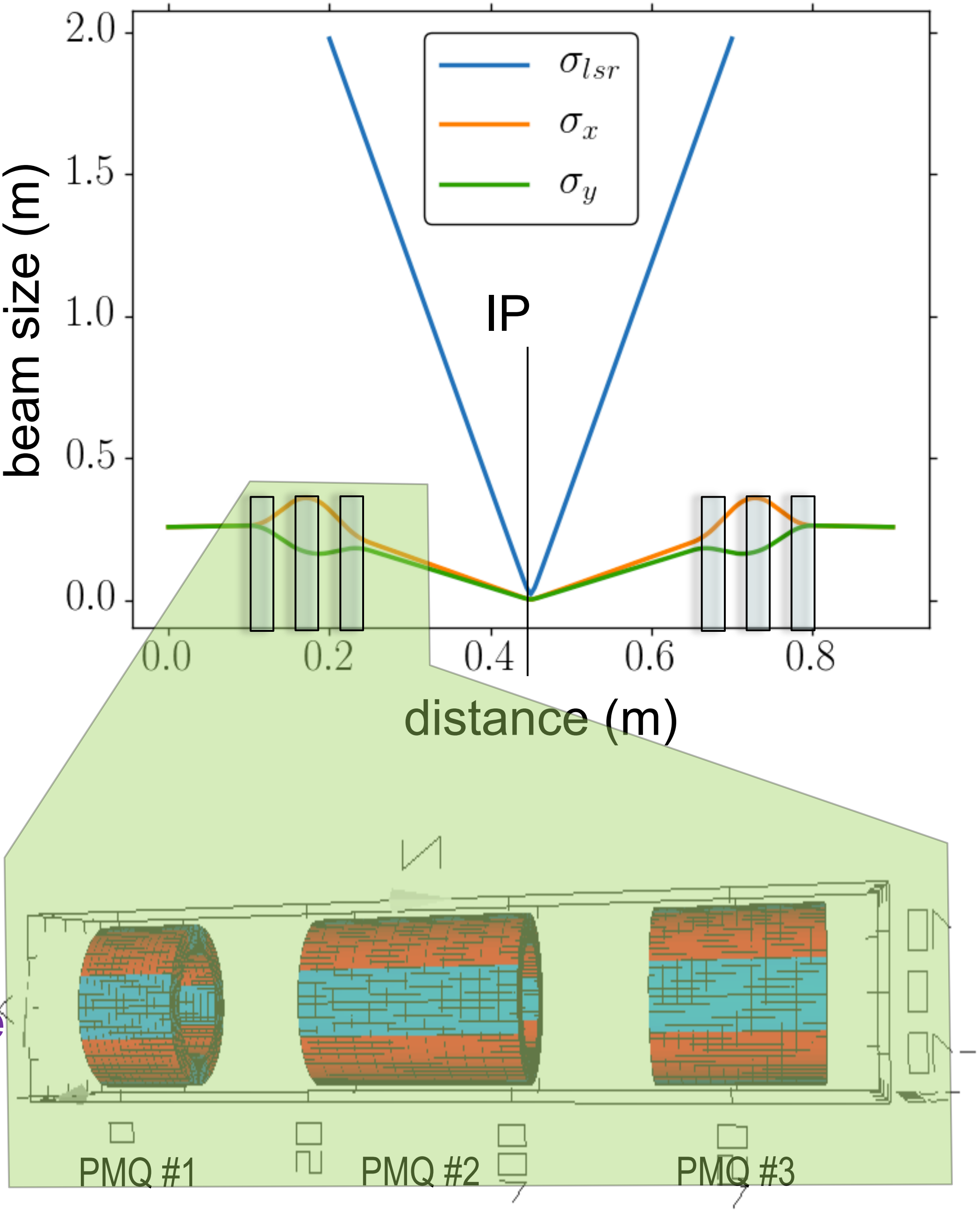
Final focus

- Interaction point (IP) simulated
  - Beam/laser spot sizes ~ $10\ \mu m$



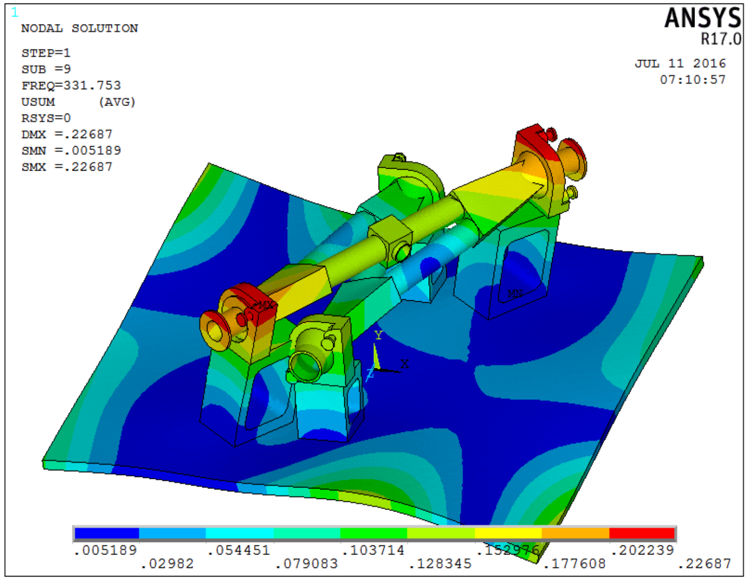
we are here

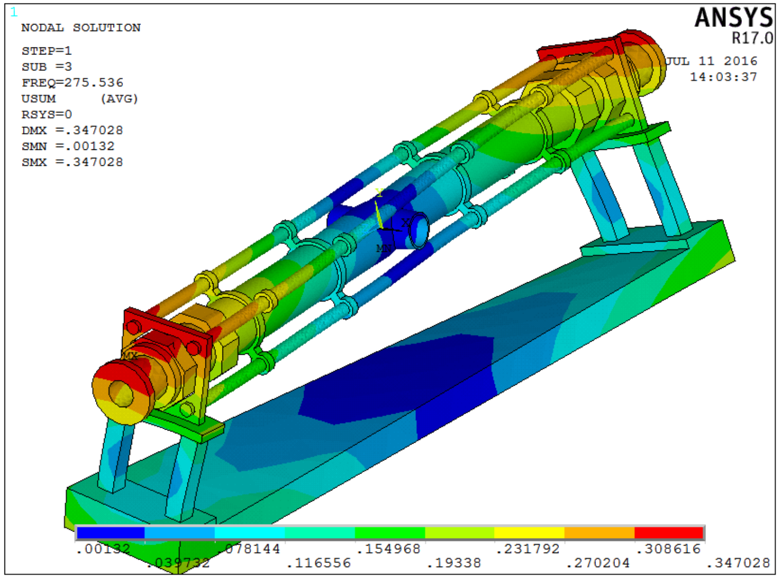




Challenges with Coherent enhancement cavity R&D

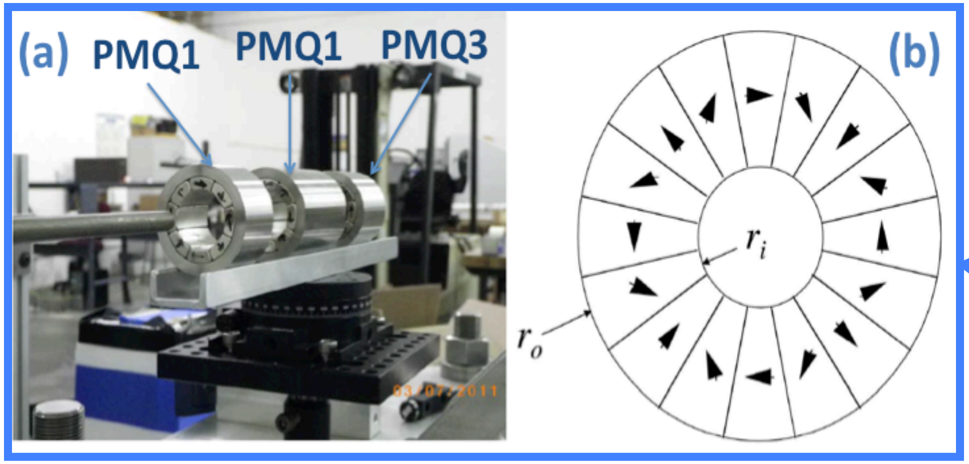
- Repetition rate is 3 MHz (i.e. 100 m bunch separation).
- Need to design long-delay cavity (with many reflections – Heriott cell type)
- Gain achieved so far ~50

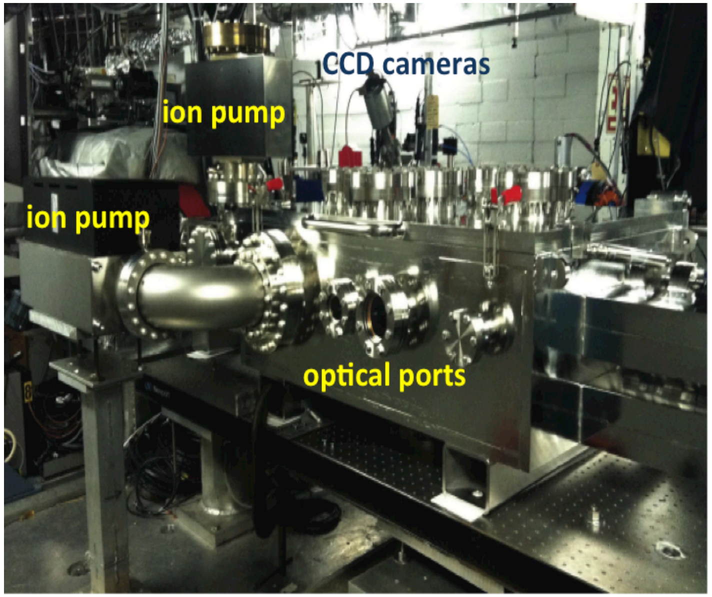


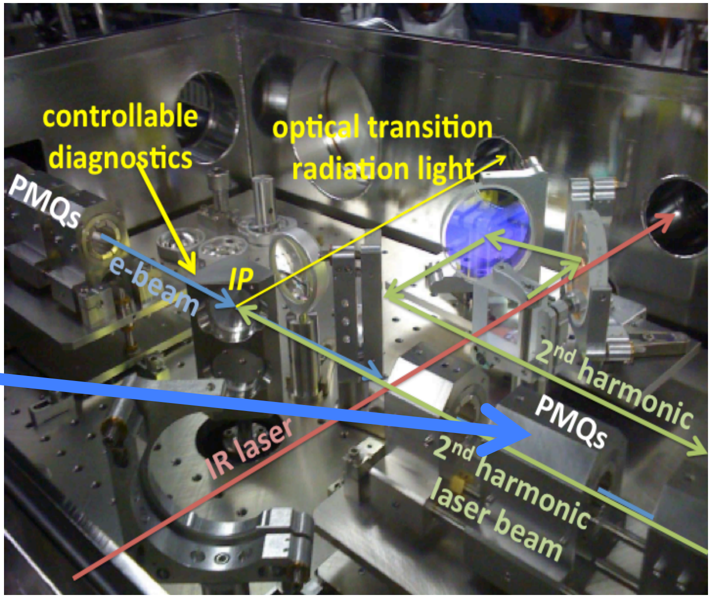


Interaction area

- UHV chamber
- final-focus quadrupole magnets
- beam diagnostics:
  - beam size measurement
  - laser/e- beam synchro.







Chambers constructed by Radiabeam for another facility

ICS timeline

- Currently upgrading laser system (one amplifier to ~mJ level)
- Acceleration to 300 MeV in FY17
- Installation of ICS experiment planned in 2018
- Preliminary test of subsystems (quad + diagnostic) will occur before then and as time permits

- First collision expected early 2019

Summary

- The FAST facility at Fermilab could support R&D on X and gamma ray sources respectively based on channeling and inverse Compton scattering
- Channeling progress:
  - During commissioning of the 50-MeV injector we attempted a X-ray channeling experiment
  - Follow up experiment once the FAST facility beamline is finished
- ICS progress
  - A gamma-ray experiment in preparation
  - First scattering experiments planned early 2019

Support

- The channeling work was seeded by the DARPA AXIS N66001-11-1-4196 to Vanderbilt University & NIU
- The gamma-ray source development is funded by the Department of Homeland Security under DNDO Dn-077-ARI-94 to NIU
- Fermilab is operated by the Fermi Research Alliance LLC under contract No. DE-AC02-07CH11359 with the Department of Energy